(1) as above noticed for all collisions by introducing the factor $u - \text{U} + c\varpi$ to denote frequency of collision; or (2) for all spheres as they exist at a given instant. Now, Prof. Burnside has calculated the average rotation energy by method (2), which gives $2\text{A}\overline{\omega^2} = \frac{1}{k}$. But when he comes to the translation energy, he takes the result $\overline{(u - \text{U})^2} = \frac{2}{h}$ from Prof. Tait, not observing, I think, that that result is given by Tait as the average for all collisions per unit time. And then, equating two inconsistent things, he gets the conclusion $\frac{1}{k} = \frac{2}{h}$, or the mean energy of rotation is twice that of translation.

To be consistent, he should have given the mean of $(u - \text{U})^2$ for all pairs of spheres—that is, $\overline{u^2} + \overline{\text{U}^2} = \frac{1}{h}$. And so his result should have been $\frac{1}{k} = \frac{1}{h}$, agreeing with Maxwell

It may be interesting to see what would have been the result of introducing the factor $u - \text{U} + c\varpi$ to denote frequency of collision. The expression whose average is required would then be—

$$(u - \text{U} + c\varpi)^2\{2\varpi - c(\text{K} + k)(u - \text{U})\}.$$

As the frequency factor $u - \text{U} + c\varpi$ must be always positive, we must integrate between the limits $\text{U} = +\infty$ to $\text{U} = -\infty$, and $u = +\infty$ to $u = \text{U} - c\varpi$. After integration, we reject odd powers of ϖ.

I have worked it out to the first power of c, rejecting c^2, &c. We have, in that case, to evaluate—

$$\int_{-\infty}^{\infty}\int_{\text{U}-c\tilde{\omega}}^{\infty}\{2\varpi(u-\text{U})^2 + 4c\varpi^2(u-\text{U}) - c(\text{K}+k)(u-\text{U})^3\}\epsilon^{-hu^2}\epsilon^{-h\text{U}^2}\,du\,d\text{U}.$$

The first term gives zero. The second term gives $\frac{4c\varpi^2}{h}$, and the third term gives $\frac{2c(\text{K} + k)}{h^2}$. From which, on substitution, and integrating for ω, Ω, &c., from ∞ to $-\infty$, we easily obtain $k_1 = k_2 = \&\text{c.} = h$.

To extend the process to cases in which c^2, &c., cannot be neglected, would be difficult. But I think the *onus probandi* now lies on the other side.

S. H. Burbury.

Double Orange.

On a blood orange being cut open by my little daughter yesterday, a small orange was found inside, which, although no larger than a hazel-nut, was yet perfect in form and colour. It showed no point of difference, other than that of size, as compared with the parent orange, and there was nothing in the appearance of the uncut fruit suggestive of the miniature of itself carried within. My sole right to write upon this subject is one you have always recognized in your journal, viz. that to record an interesting fact.

Gerald B. Francis.

Katrine, Surbiton.

METALS AT HIGH TEMPERATURES.[1]

I PROPOSE this evening to consider, first, the methods of measuring high temperatures, and, second, to describe certain effects they produce on metals.

Geber, writing in the eighth century, gives directions for obtaining high temperatures, but points to the difficulties that arise in practice, "because fire is not a thing which can be measured, '*sed quoniam non est res ignis, quæ mensurari possit.*'"[2] It is not sufficient to attain temperatures that are known to be high; it is necessary, for the purpose of modern investigation, to measure them with accuracy; and few of the early chemists in this country did more in affording a basis for the study of metals at high temperatures than Robert Boyle, the application of whose well-known law to solutions of metals in each other has been made evident by recent work. The 30th of December last was the third centenary of his death; it is well, therefore, that this lecture should begin with a tribute to his memory. He suggested improvements in the ordinary mercurial thermometer,[1] constructed what would appear to be the first air thermometer with an index; and although he did not do much for thermometry at high temperatures, he appears to have been struck by what must have been a quaint device for regulating high temperatures, for he points out that "the great mechanic, Cornelius Drebel[2] made an automatous musical instrument and a furnace which he could regulate to any degree of heat by means of the same instrument." He indicates various degrees of intensity of heat by reference to the colour of a glowing mass of fuel, and says that,[3] "tho' we vulgarly say in English, 'a thing is red hot,' to express a superlative degree of heat, yet, at the forges and furnaces of artificers, by a white heat they understand a further degree of ignition than by a red one." It is not a little strange that for three centuries after his death the same vague expressions have constantly been used in describing high temperatures.

A great step in advance was made in 1701 by Sir Isaac Newton,[4] who applied the law of cooling to the measurement of temperatures beyond the range of the mercurial thermometer, and in the notes which accompany his "Scala graduum caloris" he showed that he knew that the freezing-point of lead differs slightly from its melting-point.

Eighty years later, Josiah Wedgewood (1782),[5] aided by one of my predecessors, Mr. Alchorne, Assay Master of the Mint, determined a few melting-points of metals, and, in communicating a description of his "thermometer for measuring the higher degrees of heat" to the Royal Society, we find him, one thousand years after Geber had said that "fire cannot be measured," still lamenting the want of suitable instruments, saying: "How much it is to be wished that the authors [to whom he refers] had been able to convey to us a measure of the heat made use of in their valuable processes; . . . a red heat, a bright red, and a white heat are," Wedgewood adds, "indeterminate expressions, and even though the three stages are sufficiently distinct from each other, they are of too great latitude, and pass into each other by numerous gradations which can neither be expressed in words nor discriminated by the eye." Another ninety years brings us to the last time that the measurements of high temperatures formed the subject of a Friday evening discourse in this Institution. On March 1, 1872, the late Sir William Siemens addressed you on the measurement of "heat by electricity";[6] and, speaking of the mercurial thermometer, said: "When we ascend the scale of intensity we soon approach a point at which mercury boils, and from that point upwards we are left without a reliable guide, and the result is that we find, in scientific books on chemical processes, statements to the effect that such and such a reaction takes place at a 'dull red, such another at a 'bright red, or a 'cherry red,' or a 'white heat'—expressions which remind one," he adds, "of the days of alchemy rather than of chemical science at the present day."

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[1] A Lecture delivered at the Royal Institution by Prof. W. C. Roberts-Austen, C.B., F.R.S., on Friday evening, February 5, 1892.

[2] From the edition of his "Summa Perfectionis Magisterii," p. 28, published in Venice, 1542.

[1] Boyle's Works, Shaw's edition, vol. i. p. 575, 1738.

[2] Cornelius van Drebel, 1572-1634, *loc. cit.* vol. iii. p. 38, 1738.

[3] *Loc. cit.*, vol. ii p. 28.

[4] Phil. Trans. Roy. Soc., vol. xxii. p. 824.

[5] *Ibid.* vol. lxxii. p. 305.

[6] Roy. Inst. Proc., vol. vi. p. 438, 1872.

It is not a little singular that the same lament should have been uttered, with so long an interval between, by two prominent technical men, and it suggests that but little experimental work had been done in the meantime with a view to the measurement of high temperatures. This is, however, far from being the case. A vast amount of work was done by physicists and metallurgists whose chief masters were "indefatigable labour, the closest inspection, and hands that were not afraid of the blackness of charcoal"; and their more noteworthy efforts were based on the employment of the air thermometer, in which the expansion of air replaces the expansion of the mercury in the ordinary thermometer, the bulb being of some fire-resisting material.[1] For this purpose, Princep (1827) used a bulb of gold, Pouillet (1836) one of platinum, and finally, Deville and Troost, in a truly splendid series of investigations, adopted bulbs of porcelain, with iodine vapour as the elastic fluid. They ultimately reverted to the use of air.

You will remember that old mercurial thermometers had much information, supposed to be useful, engraven on their scales, and such statements as "water freezes," "water boils," "blood heat," "fever heat," "summer heat," were considered indispensable. It is by exposure to known temperatures that a thermoscope can be converted into a pyrometer for measuring intense heat; and the air or gas thermometer has, in the hands of Deville and Troost, rendered excellent service by enabling such gradations to be effected. The gas thermometer is not, in itself, a handy appliance, for it requires much subsidiary apparatus, and elaborate corrections of various kinds have to be introduced into the numerical data it affords; but it has given many fixed temperatures—such as melting-points and boiling-points of elements, and of compounds—which may safely be made use of in graduating pyrometers. For very high temperatures, 900° C. and over, we rely on the excellent work of M. Violle[2] on the specific heats of platinum, silver, gold, palladium, and iridium, which have enabled the melting-points of the respective metals to be calculated.

The determinations of temperatures between 300° and 1000°, which are now generally accepted, also rest upon data accumulated by the aid of the air thermometer, which has thus enabled the graduation to be effected of instruments widely differing from it, that can be trusted to give rapid and accurate indications in daily use. I can only bring before you two of the many kinds which have been devised; they are, however, by far the best that are available, and for the determination of temperatures up to the melting-point of platinum, leave little to be desired—

(1) A pyrometer which depends on the increase in the resistance of a heated conductor through which a divided electrical current is passing; and

(2) One in which the strength of an electric current, generated by the heating of a thermo-junction, is used as a measure of the heat applied to the thermo-junction.

The principle of the electrical resistance pyrometer was indicated by Sir William Siemens ("Collected Papers," vol. ii. "Electricity," p. 84, 1889) in a letter addressed to Dr. Tyndall, dated December 1860, and the nature of the instrument may be made clear by the accompanying diagram, Fig. 1. A divided current passes from the battery B, to a platinum wire, C, coiled round a clay cylinder, and to a resistance coil, R. At the ordinary temperature the resistance of the platinum coil is balanced by the standard resistance R. If, however, the platinum coil be heated, its resistance will be increased, and, this increase of resistance, which can be measured in various ways, indicates the temperature of the coil C. The coil itself may be adequately protected and exposed to temperatures which have been determined by the air thermometer; the deflection of a suitable (differential) galvanometer, G, will then indicate temperatures directly. For instance, the temperature at which zinc boils has been accurately fixed at 940° C., and if the coil is heated in the vapour of boiling zinc, the angle through which the galvanometer mirror is deflected marks the temperature of 940° C.

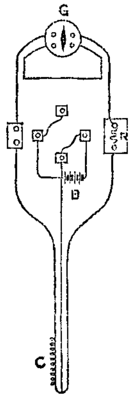

Fig. 1.

The Report of a British Association Committee showed in 1874 that the instrument is liable to changes of zero, but Mr. H. L. Callendar has recently (1887) restored confidence in the method which had been shaken by the Committee. He has proved that if sufficiently pure platinum wire be used, and if the wire be carefully annealed and protected from strain and contamination,[1] resistance pyrometers may be made practically free from changes of zero even when used at temperatures as high as 1000° C. He attributes the changes of zero to which the Siemens pyrometers are liable to the action on the wire of the clay cylinder on which it is wound, and of the iron tube in which it is inclosed. As the result of his experiments he has introduced certain modifications, which render the instrument not only trustworthy but very sensitive. He winds the platinum wire on a thin plate of mica, and incloses it in a doubly glazed tube of hard porcelain. He uses the zero method of measuring the resistance; but for these and other details of manipulation his own very interesting papers must be consulted. I will only add that I have had the pleasure of working with him in the Mint Laboratory, and I am satisfied that at temperatures about 1000° the *comparative* results afforded by his method are accurate to the tenth of a degree, a result which would certainly have been deemed impossible a year or two ago.[2]

The necessity for working with small volumes of fused metals, into which the tube of Callendar's pyrometer could not be plunged, has led me to prefer to adopt a method that would be classified under the second heading I have given. A very small thermo-junction may, in fact, be employed in such cases. The use of thermo-junctions for measuring high temperatures appears to have been suggested in 1826 by Becquerel, and adopted by Pouillet in 1836,[1] who advocates the use of iron in conjunction with platinum; but of all the varied combinations of metals and alloys which have been tried from time to time, that proposedby H. Le Chatelier possesses many advantages, on which I have elsewhere dwelt.[2] It consists of a platinum wire twisted at its end with a wire of platinum alloyed with 10 per cent. of rhodium. Such a couple may be used for some time without change of zero, and if the junction becomes injured it may be cut off, and the severed ends of the wires may be twisted together again. I am satisfied that it can afford comparative results which are accurate to 1° at temperatures of over 1000°. The diagrams given later (Figs. 4, 5, and 6) show the disposition of the apparatus. The spot of light indicating the deflections of the galvanometer needle is caused, for the illustrations of this lecture, to fall onto a graduated scale 45 feet long on the wall of the theatre. The thermo-junction has been calibrated with the aid of certain known temperatures, and the long scale is inscribed after the manner of the old thermometer scales, with certain fixed points, which are, of course, far higher than those it was possible to indicate by the expansion of mercury in a glass tube. [These fixed points were: "water boils" (100°), "lead melts" (326°), "zinc boils" (940°), "gold melts" (1045°), "palladium melts" (1500°), "platinum melts". (1775°). On heating the thermo-junction to bright redness in a Bunsen flame, the spot of light moved rapidly to the point marked "zinc boils."] For laboratory experiments the scale is a short transparent one, rigidly fixed in relation to the galvanometer.

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[1] See the excellent bibliography given by C. Barus, Bull. Geological Survey, U.S.A., No. 54, 1889.

[2] *Comptes rendus*, vol. lxxxix. p. 702, 1879; vol. xcii. p. 866, 1881.

[1] Phil. Trans. Roy. Soc. vol. 178 (1887). A, pp. 161–230, and vol. 182 (1891), A, pp. 119–157; *Phil. Mag.* vol. xxxii. July 1891, p. 104, and vol. xxxiii. Feb. 1892, p. 220.

[2] As this statement has been received with some surprise, it may be as well to state briefly how this degree of accuracy and sensitiveness is attained. The resistance-box is compensated for changes of temperature, and changes of resistance in the wires leading to the pyrometer are automatically eliminated. The resistance itself is measured by a modification of the well-known Carey-Foster method. The balancing resistance of the Wheatstone bridge employed, is composed partly of resistance coils and partly of a bridge-wire along which a contact key slides. The resistance of a centimetre of this wire is made to correspond to the increase of resistance of the pyrometer produced by a rise of 1° C. The galvanometer can easily be made sensitive to one-hundreth of a centimetre of this bridge-wire, so that one-tenth of a centimetre, which corresponds to one-tenth of a degree, can, of course, be measured with certainty.

In leading up to the experiments which follow, in the course of which metals will be exposed to high temperatures, I would remind you that if an ordinary thermometer be plunged into water which is gradually losing its heat to a cold environment, the mercury will fall until the water begins to freeze, but directly this happens the mercury remains stationary until all the water is frozen; so that if the rate of fall be measured with a chronograph, there will be a steady fall to the freezing-point of water, then a long arrest, followed by a renewed fall. If these readings be plotted, a well-known time-temperature curve will be obtained. Exactly the same effect is produced when a fluid metal "freezes," and before proceeding further it may be well to determine experimentally the freezing-point of gold. Beneath this little mass of pure gold, A (Fig. 2), a thermo-junction, B, is protected by a very thin layer of clay from the metal. The oxyhydrogen flame is made to play on the gold, there is a rapid movement of the spot of light over almost 25 feet of the scale, there is a diminution in the rate of rise near the point marked 1045°, the melting-point of gold, and then, when the metal becomes fluid, the temperature rapidly rises as more heat is given to the little mass. The source of heat is now removed, the temperature falls, there is an arrest just at 1045° C., the freezing-point of gold, and then the spot of light resumes its course as the gold cools down to the temperature of the room. The melting-point and freezing-point of palladium, 1500° C., were then shown in the same way. It should be observed, however, that when a small fragment of palladium is fused in the naked flame of the oxyhydrogen blow-pipe, hydrogen appears to be absorbed by the metal; and this absorption of gas lowers the freezing-point materially, and makes it far less steady than when a fresh piece of metal, cut from a large mass is fused for the first time.

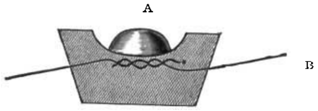

Fig. 2.

When the spot of light is allowed to fall on a sensitized plate in a suitable camera,[1] the time-temperature curve traced on a moving plate will be of the form shown in Fig. 3.

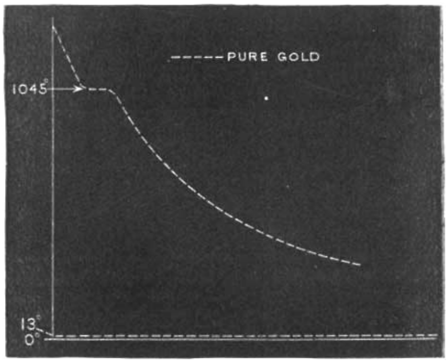

Fig. 3.

It may be useful to show the method by which these autographic curves are obtained: the following diagram, Fig. 4, is therefore added.

The arrangement consists in inclosing a galvanometer of the Deprez and d'Arsonval type in a large camera; a fixed mirror, F, being placed below the movable mirror, M, of the galvanometer, so that the light, from the lime cylinder L, reflected in the mirror H, passes to both mirrors, F and M, and is reflected in the direction of a fine horizontal slit, A B, behind which a sensitized photographic plate, C, is drawn vertically past the slit, by means of gearing, D, driven by clockwork. The ray from the fixed mirror is interrupted periodically by the vane E, and a beaded datum line is given, which enables any irregularity in the advance of the plate to be detected.

The amount of divergence from its datum line of the spot of light reflected by the movable mirror at any given moment bears a relation (which can readily be found by calibration) to the temperature to which the thermo-junction X is heated, and the variations of temperature are recorded by a curve which is the resultant of the upward movement of the plate and the horizontal movement of the spot of light. A crucible, *c*, which may be filled with molten metal, is provided with a tubulure, T, for the insertion of the thermo-junction. The crucible is suspended by wires in a double jacket of tin plate, *a b*.

It will have been evident that the thermo-junction of platinum and platinum-rhodium could not be used for measuring temperatures higher than the melting-point of the platinum of which it is made. Metals with higher fusion-points than platinum are, however, available; thus iridium will only just melt in the flame produced by the combustion of pure and dry hydrogen and oxygen. By the kindness of Mr. Edward Matthey, a thin rod of iridium has been prepared with much labour, and it can be used as a thermo-junction with a similar rod of iridium alloyed with 10 per cent. of platinum. The junction may be readily melted in the electric arc, and by this means a temperature may be registered which careful laboratory experiments show to be close to 2000°, and this agrees with the estimate of the melting-point of iridium which Violle [2] deduced from calorimetric experiments. [This experiment was shown, a different scale being employed for the screen, as the thermo-electric constants of the iridium, and iridium-platinum couple, are different from those of the platinum and rhodium one previously used.]

It is interesting to remember that within a year in this Institution temperatures ranging from − 200° to + 2000°

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[1] *Comptes rendus*, vol. iii. p. 782, 1836.
[2] British Association Lecture, NATURE, vol. xli., 1889, pp. 11–32; Report Inst. Mech. Eng., Oct. 1891, p. 543.

[1] Proc. Roy. Soc., vol. xlix., 1891, p. 347.
[2] *Loc. cit.*

have been mapped out, the lower temperature by Prof. Dewar in his memorable Faraday Lecture: the higher point is now measured in public for the first time.

How difficult it is for us to realize what this range of temperature really means, for we have but little power of appreciating temperatures beyond those we can conveniently bear. We, perhaps, know the meaning of extreme cold better than great heat, but even the vivid imagery of Dante, who might have been expected to afford some guidance, gives us singularly little help. I think in depicting the terror of torture inflicted by extreme cold he succeeds better than when he describes the suffering of those who are exposed to flames. His words (Canto xxxiii.)—

> "Blue, pinched, and shrined in ice the spirits stood"—

mark the highest suffering drawn in the "Inferno." It is, however, probable that my failure to appreciate the descriptive powers of Dante may be the result of resentment, for I read with regret that he consigns to the tenth chasm of Hell, not only the coiner who

> "falsified
> The metal with the Baptist's form impressed,"[1]

but also an honest metallurgist, Cappoccio of Sienna, who,

> "by the power
> Of alchemy, . . . aped creative Nature by his subtle art";

and, I think, deserved a better fate.

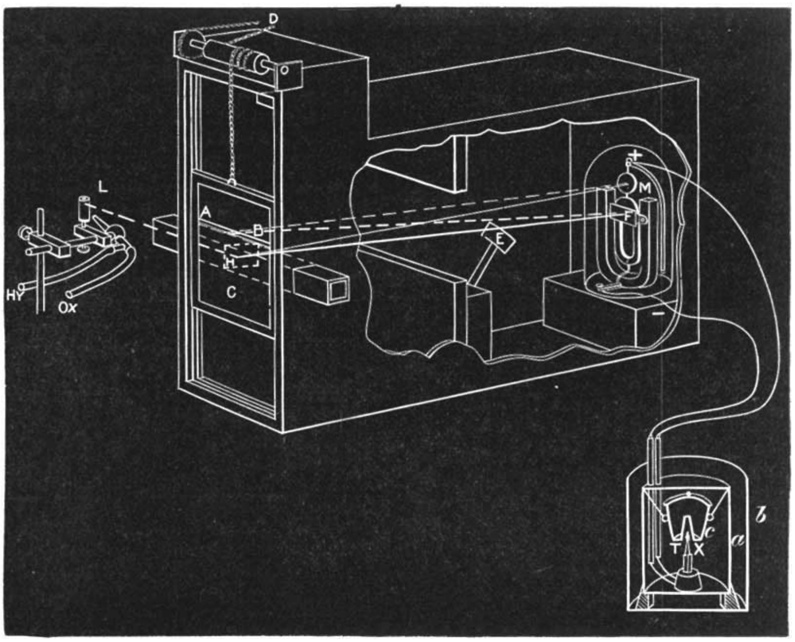

FIG. 4.

We are now in a position to consider certain other effects of high temperature on metals. Many years ago, my colleague Mr. Lockyer, and I, conducted an investigation on the spectra of the vapours of certain metals[2] at the highest temperatures we could produce, with the aid of the oxyhydrogen flame. We distilled silver, zinc, cadmium, and volatilized iron and other metals, from a lime crucible, and caused their vapours to pass into a horizontal tube of strongly-heated lime. By these experiments we satisfied ourselves that the molecular structure of metals is gradually simplified as higher temperatures are employed; and we came to the conclusion that each molecular simplification is marked by a distinctive spectrum, and that there is also an intimate connection between the facility with which the final stage is reached, the group to which the element belongs, and the place which it occupies in the solar atmosphere. At the highest temperature of the oxyhydrogen flame, molecules of metals are simplified, but their constituent *atoms* remain unchanged. Mr. Lockyer has, however, since done far more: he has shown that the intense heat of the sun carries the process of molecular simplification much further; and, if we compare the complicated spectra of the vapours of metals produced by the highest temperatures available here with the very simple spectra of the same metals as they exist in the hottest part of the sun's atmosphere, it is difficult to resist the conclusion that the *atom* of the chemist has itself been changed. My own belief is that these "atoms" are changed, and that iron, as it exists in the sun, is not the vapour of iron as we know it upon earth. We will not dwell in this lecture on the effects of very high temperatures on metals, but rather on the influence of comparatively low temperatures—that is, below whiteness—in changing the number and arrangement of the atoms in metallic molecules. A profound change must occur when the viscous form of sulphur passes spontaneously at the ordinary temperature into the yellow crystalline variety, but the change is accompanied by but little thermal disturbance. In the case of metals there is also abundant evidence that molecular change may take place at low temperatures. Take the fusible alloy of bismuth, lead, and tin, which bears Newton's name, and contains—

Bismuth	50·00
Lead	31·25
Tin	18·75
	100·00

It fuses at 90°; it may be cast round a thermo-junction, and plunged in water and cooled thoroughly until the observer is certain that the mass has returned to the atmospheric temperature: take it out of the water, dry it rapidly, and in a few moments it will become too hot to hold. The "fracture" of the metal is totally different before and after the molecular change, which is the cause of this evolution of heat, has taken place. The change, moreover, takes place in the solid metal, and is not due to the release of the latent heat of fusion. The mass, solid as it appears to be, must be the scene of an internal struggle between the molecules in the effort to attain a state of equilibrium, and this conflict is but a type of the action that takes place in many metals and alloys which are of vast industrial importance.

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[1] The golden florin of Florence.
[2] Proc. Roy. Soc., vol. xxiii. p. 344, 1875.

Time will only permit me to deal with three cases of the action of high temperatures on atoms and molecules of metals. In the first case, the *arrangement* of the atoms in the molecule of a metal, iron, is disturbed, and the result is of great industrial importance. In the second case, the atoms of a metal, gold, appear to *combine* with those of another metal; and the result, while it is mainly of interest in connection with the history of science, has nevertheless an important bearing upon art. The third case relates to the *molecular bombardment* which takes place when a small quantity of metal is dissolved in a mass of a metallic solvent, and is of interest in connection with modern views both as to osmotic pressure and solution generally.

(1) The pyrometric couple is inserted in the centre of a little mass of steel, which is being slowly raised to a bright red heat; when the flame is withdrawn, the spot of light will return towards the zero end of the scale, falling slowly until a temperature of 655° is reached, and then there will be an abrupt and prolonged arrest. The metal has never been near its melting-point, and the evolution of heat must be due to a molecular change in the solid metal. In the case of this particular sample of steel, the evolution of heat is mainly the result of a change in the relation between the carbon and the iron; but by laboratory experiments and careful chronographic records, Osmond has shown that, in the case of certain varieties of steel, it can be demonstrated that what here appears as a single change, attended by an evolution of heat, is really an exceedingly complex one. I have shown that it occurs in the purest iron the chemists can prepare by electrolysis, and I agree with Osmond in believing that the change which occurs in pure iron at 855° is a molecular one, independent of the presence of impurity. If the mass of steel (Fig. 5, *a*) be heated again and allowed to cool, you will observe that the point of "recalescence" appears to be that at which the iron regains its magnetic property;[1] for a magnetized needle, *b*, is attracted at the moment the arrest of the spot of light on the pyrometer scale marks the temperature at which the change occurs, and at that precise moment a second spot of light from a mirror, mounted on the magnetic needle, will rapidly move away from its zero. I have elsewhere[1] dwelt on the importance of the molecular change in iron and steel, and can now only summarize the significant facts.

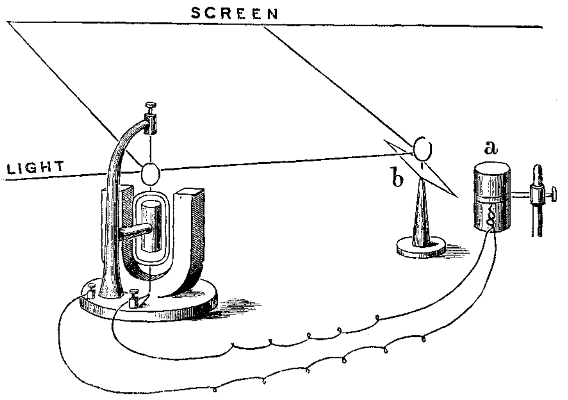

Fig. 5.

It is unnecessary to point to the extreme industrial importance of the property steel possesses, of becoming hard when it is quenched from redness in a fluid which will abstract its heat with more or less rapidity.

The changes which take place at 855° and 650° have to be arrested, as it were, by rapidly cooling the mass of steel; and if this is done, the steel will be more or less hard according to the rapidity with which the progress of the molecular change has been stopped. It is, however, useless to attempt to harden steel if the temperature of the mass has fallen below 650°. In "oil hardening" or cooling a large mass of steel, like the "A" tube of a gun, which may be 30 feet long, great care should be taken to insure that the temperature of the mass is as uniform as possible; for, if part of the mass is hotter than 650°, while part is colder, the oil will really be cooling a mass of steel which is itself passing through various stages of complex molecular change, and the operation of "hardening" arrests, as it were, the atoms in the midst of a conflict incidental to their attempt to group themselves into one or other of the molecular modifications of iron. By cooling a mass of steel which is not at uniform temperature, stresses of great complexity and intensity are set up, stresses that may greatly reduce the effective strength of the gun.[2] The result is told in failures, by which many lives have been sacrificed; but I need hardly say that the Director-General of Ordnance is fully sensible of the national importance of studying the behaviour of iron and steel at high temperatures, and, at Dr. Anderson's suggestion, the Institution of Mechanical Engineers appointed a Committee, and have intrusted me with a large portion of the inquiry.

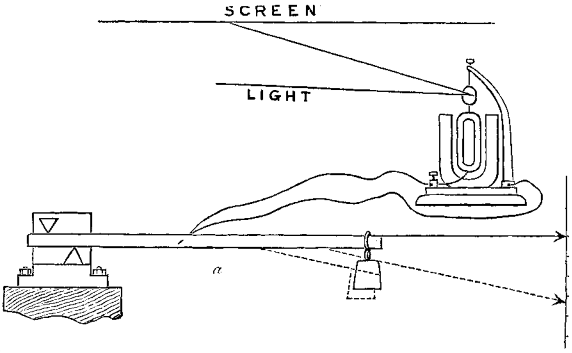

Fig. 6.

In the next experiment, Fig. 6, a bar (*a*) of steel, ½ inch in section and 18 inches long, was heated to bright redness and fixed firmly at one end; a weight of about 2 pounds is rapidly hung to the free end, a light pointer is added to magnify the motion of the bar, and the thermo-junction is rapidly introduced into a small hole drilled in what is arranged to be the hottest part of the bar. The bar is not softest at a red heat; it remains perfectly rigid until it has cooled down to dull redness, and the temperature, as measured by the spot of light from the galvanometer, shows that "recalescence" has occurred. At that moment of molecular weakness in the bar, the weight has power to bend it, and the pointer falls. By such experiments the exact temperature at which the metal becomes weak, in different varieties of steel, can readily be determined.

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[1] The temperature at which these molecular changes take place in iron and steel was first demonstrated to an audience in my Newcastle lecture, 1889; but my friend Prof. Reinold, of the Royal Naval College, first arranged an experiment for lecture purposes which showed the magnetic change simultaneously with the thermal one.

[1] Report to the Institution of Mechanical Engineers, Proceedings, 1891, p. 543.

[2] "Internal Stresses in Cast Iron and Steel," by Nicholas Kalakoutsky, 1888.

(2) Evidence will now be given in support of the second case it was proposed to treat, and it will be shown that at high temperatures the atoms of metals may truly combine with each other; in fact, taking gold as a basis for the experiments, compounds may be formed which would, had they been known centuries ago, have strangely affected the history of science. When the alchemists subjected the metals to high temperatures, their efforts were mainly directed to the discovery of some substance that would either change base metals to the colour of gold, or would give them the brilliancy of silver. The mediæval chemists believed that there were two distinct substances that would effect this, "one for the white" and another "for the red." Many of their writings might be quoted in support of this view, but a reference to Geber, who wrote in the eighth century, will be sufficient. He pointed out that the transmuting agent "has a tincture of itself so clear and splendid, white or red, clean and incombustible, stable and fixed, that fire cannot prevail against it; . . . and a property of the medicine is to give a splendid colour, white or intensely citrine," to metals to which it is added.

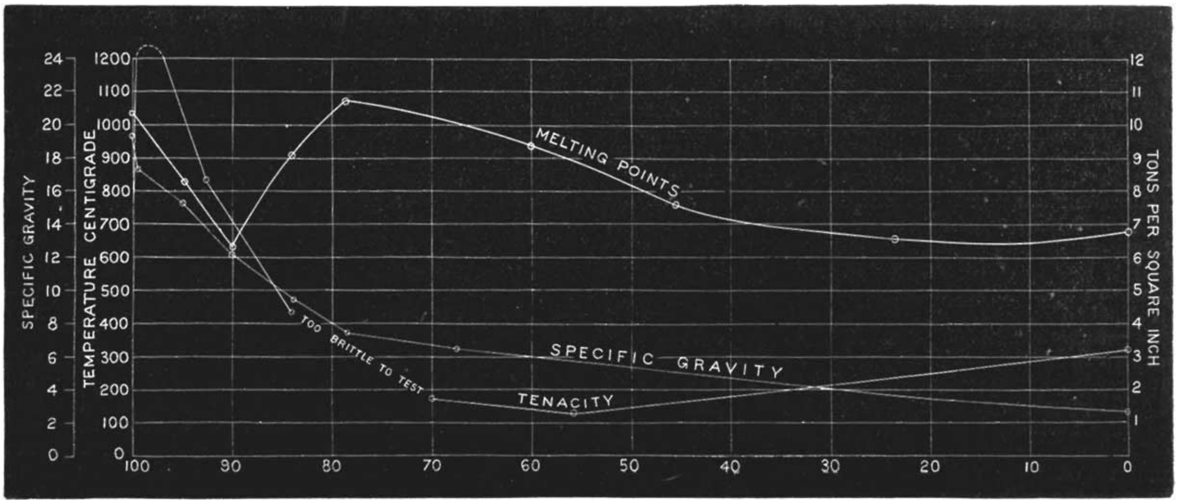

Fig. 7.

That was the effect expected from the transmuting agent, but do not think that the attempt to produce gold arose entirely from the love of gain. The colour of gold and purple impressed men strangely, and the search for the transmuting agent was most eagerly pursued in times when people lived for art, in a dream of colour. The effort to find the secret of the tint of gold is due to the same impulse which made the French in the thirteenth century manifest a keen "sensitiveness to luminous splendour and intensity of hue," so that, as Sir Frederic Leighton tells us, "a stained glass window, by Cousin, was limpid with hues of amethyst, sapphire, and topaz, and fair as a May morning." The chemists were able to stain glass ruby and purple with gold: why should they not impart the same glories to metals? I could not hope to interest you in what follows, did I not call artists to my aid; and many will remember the glowing words Mr. Ruskin uses,[1] calling purple a "liquid prism and stream of opal," reminding us of the crimson and purple of the poppy, the scarlet and orange of fire and the dawn. No wonder he chides us with turning the lamp of Athena into the safety-lamp of the miner, and with getting our purple from coal instead of, as of old, from the murex of the sea; "and thus grotesquely," he says, "we have had forced on us the doubt that held the old world between blackness and fire, and have completed the shadow and the fear of it by giving to a degraded form of modern purple a name from battle—'Magenta.'"

You will remember that Faraday showed that gold, when finely divided, is brilliantly coloured scarlet and purple. Here is a solution of chloride of gold. Add a little dissolved phosphorus, and the gold is precipated in an extremely fine state of division, which tinges the solution crimson, but if you try to remove this suspended gold you will only gain a brownish mud. However, I will give you the secret by which anyone who possesses a blow-pipe, a bead of gold, and a fragment of one of the most widely-diffused metals, aluminium, may stain gold purple through and through. But if you add aluminium to molten gold, you obtain many things, as this coloured diagram and series of specimens show. [This diagram cannot be reproduced without colour.]

The series of specimens showed that as the proportion of aluminium is increased, the golden colour of the precious metal is lessened, and when an alloy is formed with about ten per cent. of aluminium, the fractured surface of the mass is brilliantly white: from this point forwards, as aluminium is added, the tint deepens, until flecks of pink appear, and when seventy-eight parts of gold are added to twenty-two of aluminium a splendid purple is obtained, in which intense ruby-coloured opaque crystals may readily be recognized. Then, as the quantity of aluminium is still further increased, the alloys lose their colour, and pass to the dull grey hue of aluminium itself. Perhaps the most remarkable point about the purple alloy is its melting-point, which I have shown to be many degrees higher than that of gold itself.[1] See diagram, Fig. 7, in which curves of several constants of these alloys are given. This fact affords strong evidence that the alloy $AuAl_2$ is a true compound, having analogies to the sulphides, for in every other series of alloys the melting-points of all the members of the series are lower than that of the least fusible constituent. There is one other fact of much interest connected with this alloy. When it is treated with dilute hydrochloric acid, chloride of aluminium is formed, and gold is released in a singularly voluminous form. The heat of formation of the gold-aluminium alloy has not been determined, but hydrochloric acid, which will not attack gold, will readily split up this compound, of which more than three-fourths is gold; the compound, in fact, behaves like a distinct metal, having special heats of oxidation and chlorination of its own.

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[1] "The Queen of the Air," ed. 1887, p. 129; *Times*, December 11, 1891.

[1] Proc. Roy Soc., vol. l., 1891, p. 367.

(3) Lastly, we come to the question of solutions of metals in each other. One very remarkable instance of the behaviour of metals at high temperatures reveals the fact that the presence of a small amount of a metal in a mass of another lowers the freezing-point of the mass. In the industrial world this has long been known. Cellini tells us, for instance, that when the bronze for his great figure of Perseus, at Florence, was running out of the furnace, it suddenly showed signs of setting, and he therefore threw pewter plates and dishes into the ducts through which the metal had to pass—"a thing," he says, "never before done." The fluidity of the metal was immediately increased, and he found every part of the casting "to turn out to admiration."

The excellent work of Heycock and Neville,[1] on the lowering of the freezing-points of metals, by the addition of other metals, should, I would suggest, form the subject of a lecture in this Institution at an early day. I cannot attempt to deal with the matter here. In leading up to these questions of solution, as applied to metals, I would remind you that Lord Rayleigh told us a few evenings since that it was by no means certain that a gas rushing into a vacuous globe ever completely fills it, as there may still be tiny spaces into which "odd molecules" fail to find room to vibrate in. If it is difficult for a gas to entirely fill a vacuous space, you would think it impossible for a small quantity of a metal to rapidly permeate a fluid mass of another metal; nevertheless, so far as analysis can detect, this does happen.

It may be incidentally observed that the relations of the ordinary gases to metals are far more intimate than they were formerly supposed to be, and this was proved by Graham's work on the absorption of gases by metals, which has often been dealt with in this Institution. To take only the case of iron, more than twenty years ago Sir Lowthian Bell showed that carbonic oxide can carry away iron, which is released when the temperature is raised. Ludwig Mond and Langer have since isolated most interesting compounds of iron and carbonic oxide. But to return to the solution of metals in metals.

The method of taking autographic curves of the cooling of masses of metal has already been indicated in Fig. 4,[2] and they ought to enable much information to be gained as to what is taking place throughout the mass. Such curves should render it possible to ascertain which of the rival theories as to the nature of solution, as applied to salts, is supported by the behaviour of a metal dissolved in a metal. When, for instance, a little aluminium dissolves in gold, is the analogue of a hydride formed, and, if so, is the curve of freezing-points of a series of aluminium-gold alloys a continuous one? On the other hand, does the theory advocated by van 't Hoff, Arrhenius, and Ostwald gain support, and do the molecules of the dissolved metals act independently of the solvent—that is, does *osmotic* pressure come into play? It will be remembered that the law which regulates osmotic pressure has exactly the same form as Boyle's law—that is, the pressure is proportional to the density of the gas or of the solution. Is the view of Arrhenius correct—that, if a solution be very dilute, the molecules of the dissolved substance are dissociated, act independently of each other, and behave like a perfect gas?

It will require years of patient work before these questions can be answered; but it appears certain, from the admirable experiments of Heycock and Neville,[1] to which reference has already been made, that, taking metals with low melting-points (such as tin or lead) as solvents, the lowering of the freezing-point of the solvent is really due to the bombardment exerted by the molecules of the dissolved metals.

I have extended this investigation by employing as a solvent a mass of fluid gold, which has a high melting-point, and is not liable to oxidation, and the results confirm those obtained by Heycock and Neville.

There is yet one other question: When metals are added in small quantities to a metallic mass, may the solvent remain inert? Here is a mass of 1000 grammes of lead, and to it 15 grammes of gold, or 1·6 atoms for every 100 atoms of lead, will now be added. It could be shown that the gold is readily dissolved, and remains dissolved, even if the lead be solidified. Now, to the fluid lead sufficient aluminium will be added to form the purple alloy with the dissolved gold; the mass will be well stirred, but the aluminium will not unite with the lead; it will nevertheless find out the gold, and, after uniting with it, will carry it to the surface of the bath. Thence it can be removed, and the purple colour of the alloy identified, or the gold it contains can be revealed by the method Prof. Hartley[2] has given us for detecting the presence of gold in an alloy by volatilizing the alloy in a torrent of sparks from an induction coil, and condensing the vapour on mica.

The union of the aluminium and the gold must, however, be peculiar. Crookes[3] has shown that when this alloy is used as an electrode in a vacuum tube, the gold is volatilized from the alloy and deposited as a film on the glass, leaving the aluminium behind.

The purple alloy presents us with the most interesting case yet known of a molecule built up of purely metallic atoms, but we are certain that the atoms are still those of gold and aluminium—that is, the atoms of the united metals remain unchanged. The interest in this substance is deepened if it be remembered that our aim at the present day is the same as that of the alchemists, for we are striving, as they did, to attack and change the chemist's *atoms* themselves. We seek, as truly as they, to effect the transmutations, which, as Boyle said, would "be none the less real for not being gainful," and employ high temperatures in the hope of simplifying the molecular structure of metals. We no longer consider gold to be the "sum of perfection," but still retain the belief expressed by Geber, eleven hundred years ago, that, "if we would change metals, we must needs use excess of heat." A poet also appears to have felt this, for George Herbert writes in the seventeenth century—

> "I know . . . what the stars conspire,
> What willing Nature speaks, what forced by fire";

thus comparing the ordinary response of Nature to the investigator with the evidence he elicits from her by heat.

By fusing gold, and staining it "the purple of the dawn," a new interest has been given to the metal which the alchemists always connected with the sun; and for further proof that metallic atoms may be changed, we must turn to the sun itself, as to a great metallurgical centre, where "all the elements shall melt with fervent heat."

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[1] Chem. Soc. Journ., vol. lv., 1889, p. 666; vol. lvii., 1890, pp. 376, 656; vol. lix., 1891, p. 936.

[2] Proc. Roy. Soc., vol. xlix. p. 347, 1891.

[1] *Loc. cit.*

[2] Proc. Roy. Soc., vol. xlvi., 1889, p. 88.

[3] Proc. Roy. Soc., vol. l., 1891, p. 88.